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BACKGROUNDS and ARTIFICIAL LIGHTING

For Standardized Grain Inspection

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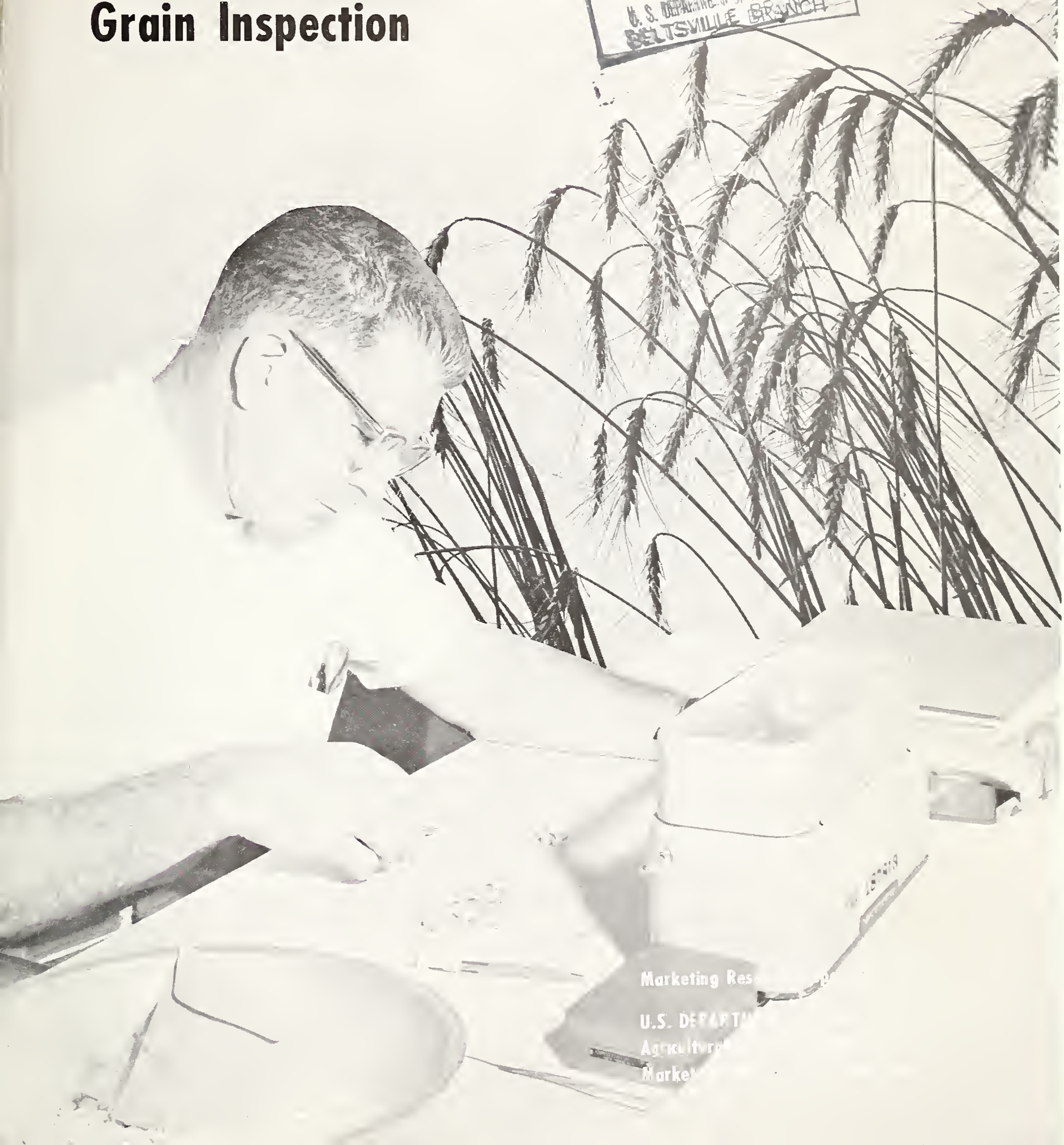

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Jane E. Gates, food technologist, Harold Kramer, agricultural engineer, and Robert A. Johnson, research chemist, of the Market Quality Research Division of Agricultural Marketing Service, also participated as panelists.

Dorothy Nickerson, head, Standards Section, Standardization Branch, Cotton Division, Agricultural Marketing Service, Washington, D.C., conducted the color aptitude tests for all panelists. She also gave permission to reprint figures 1, 2, and 3, which originally appeared in Opt. Soc. Amer. Jour. 50(1): 56–69, 1960.

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SUMMARY

The accuracy of grain inspection depends heavily on proper lighting. Even where daylight can be used, it changes with the hour and the weather. And the volume of grain shipments and handling has increased so much that many inspection offices are in use 24 hours a day. The need, therefore, is to have artificial lights that will give adequate illumination of constant quality approaching natural daylight as nearly as possible.

Four artificial light sources were compared for their accuracy in rendering color in comparison with an accepted standard artificial north sky daylight (7,500° Kelvin). Light sources were arranged to provide an intensity of 130 foot-candles with an angle of view of 45°. The interior of the testing booths was painted a neutral gray.

The four illuminants were: Special fluorescent combined with incandescent: a combination of daylight, cool white, and blue fluorescent; cool white fluorescent: and daylight fluorescent.

Two similar series of color chips were compared under the standard lamp and the test lamps. These two series of color chips varied only in lightness level, and comprised the colors of wheat. A third series at a higher lightness level and different hue was chosen to comprise the colors of corn. An individual series consisted of 16 color chips (each 3 by 4 inches), arranged from a hue of longer wavelengths to a hue of shorter wavelengths vertically, with increasing intensity horizontally.

Panelists were screened for color aptitude before their participation.

In a test, a panelist stood at the juncture of the booth containing the standard lamp and an adjoining booth containing one of the test lamps. One of the three panels of color chips was placed under the standard lamp. The operator, or panelist, was given color chips and asked to place them on a blank panel corresponding in size and arrangement to the color panel. The position of each test chip was recorded. Individuals were presented, at random, all color chips twice. Eighteen operators participated in the study and, of these, six were in the group that repeated the entire test twice. Processing the data from about 4,500 observations showed that test light No. 1 most closely approximated the standard light. Operators failed consistently to place the color chips correctly when viewed under any of the other three test lamps.

Concurrent with the testing of light, the effect of background color on the ability of skilled inspectors to differentiate among the several classes of wheat was studied. The initial series of background colors were painted on fiberboards: gloss of the paint and texture of the board made it difficult for the panelists to view the grain on the background. However, the data indicated that inspectors could classify wheat samples somewhat better on colors complementary to the wheat color than on the buff-colored plastic currently used as the standard background.

BACKGROUNDS AND ARTIFICIAL LIGHTING FOR STANDARDIZED GRAIN INSPECTION

By C. H. Kingsolver, J. N. Yeatman, R. A. Boller, and J. A. Thompson[1]
Market Quality Research Division, Agricultural Marketing Service

INTRODUCTION

The accuracy of grain inspection depends heavily on proper lighting. Even where daylight can be used, it changes with the hour and the weather. And the volume of grain shipments and handling has increased so much that many inspection offices are in use 24 hours a day. The need, therefore, is to have artificial lights that will give adequate illumination of constant quality approaching natural daylight as nearly as possible.

Inspectors are asked to make subclass determinations based on very minor differences in color and appearance. For example, wheat is divided into seven classes which are, to a great extent, divided on the basis of color and texture. The inspector must be able to identify dark, hard, and vitreous kernels in Hard Red Winter wheat and Hard Red Spring wheat; amber kernels in Durum wheat; hard kernels in White wheat and kernels of Soft Red Winter wheat, Red Durum wheat, and White Club wheat. In other grains, such as barley and oats, it is necessary for the inspector to determine weathered or stained grains. Seed color is important in soybeans, off color in dry edible beans, and "bleach" in dry field peas. The degree of whiteness or creaminess and the degree of yellowness in determining the extent of parboiling in rice are of primary importance in rice inspection. There are many other inspection procedures in which accurate determinations of color are of primary importance, but these examples illustrate the importance of an accurate and standard illumination system in grain inspection.

BACKGROUND OF RESEARCH

A number of workers (*2, 3, 4, 5, 8, 9*)[2] have shown the effect of illumination upon the color evaluation of agricultural commodities and the need for controlled conditions. Nickerson (*5*), particularly, showed the effect of various artificial light sources upon color rendering, and in an earlier work (*4*) established grading procedures based on the use of standard colors viewed under artificial illumination designed to approximate natural daylight. Wegener, Thompson, and Fenn (*8*) reported studies which showed that a source of artificial illumination can be substituted for natural daylight in the judging of the color of canned tomato juice. They pointed out, as have others, that the use of artificial sources should increase the accuracy of color judgment by eliminating the use of uncertain and constantly changing natural daylight. Gould (*2*) pointed out in 1952 that an artificial daylight source had many outstanding advantages, principally the advantage of constant color quality (color temperature and intensity from to hour and from day to day).

The spectral energy distribution curves shown in figures 1, 2, and 3 represent the similarities and dissimilarities of various sources of illumination referenced to the standard for daylight at 7,400° Kelvin (as determined by Abbot and Gibson).

As Evans (*1*) states, color is a complex problem which may be divided into three parts. The first part is the light source, the second the colored surface, and the third is the way the eyes and the mind of the viewer react to the other two.

Figures 1, 2, and 3 show sizable differences in the spectral energy curves of several light sources which may be compared to natural daylight, but certain illuminants compare favorably. The similarity of the filtered incandescent and examolite fixtures and the response of viewers to energy from these sources in large scale tests led Nickerson (*5*) and others (*2, 3, 8*) to suggest the artificial

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[1] Dr. C. H. Kingsolver, plant pathologist, formerly Field Crops and Animal Products Branch, now with U.S. Army Biological Laboratories, Fort Detrick, Md. J. N. Yeatman, food technologist, Horticultural Crops Branch; and R. A. Boller, botanist, and J. A. Thompson, marketing specialist, now retired, Field Crops and Animal Products Branch.

[2] Italic figures in parentheses refer to Literature Cited, p. 21.

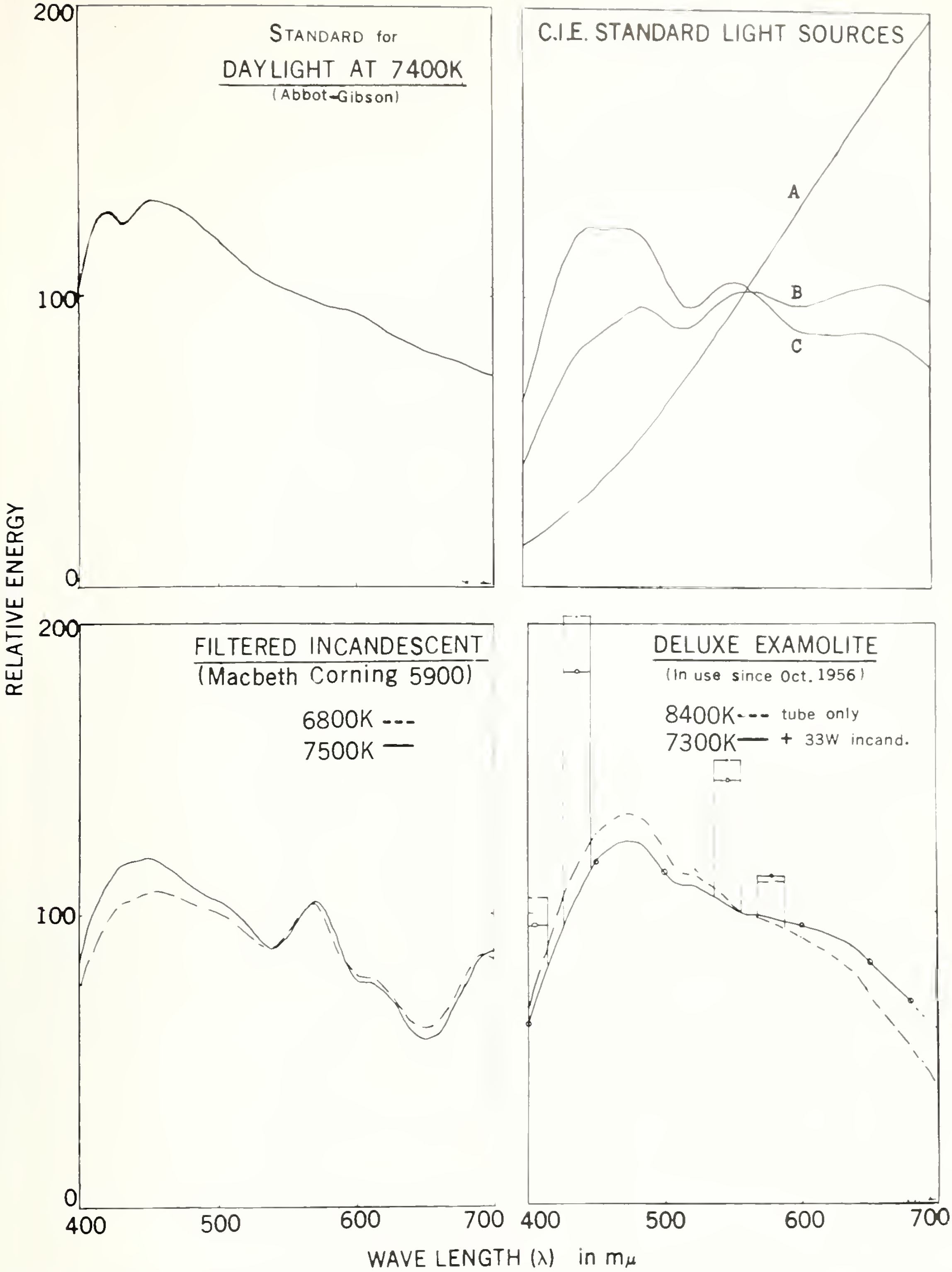

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FIGURE 1.—Relative spectral energy curves for light sources in daylight range, with C.I.E. (International Commission of Illumination) standards A, B, and C, for comparison.

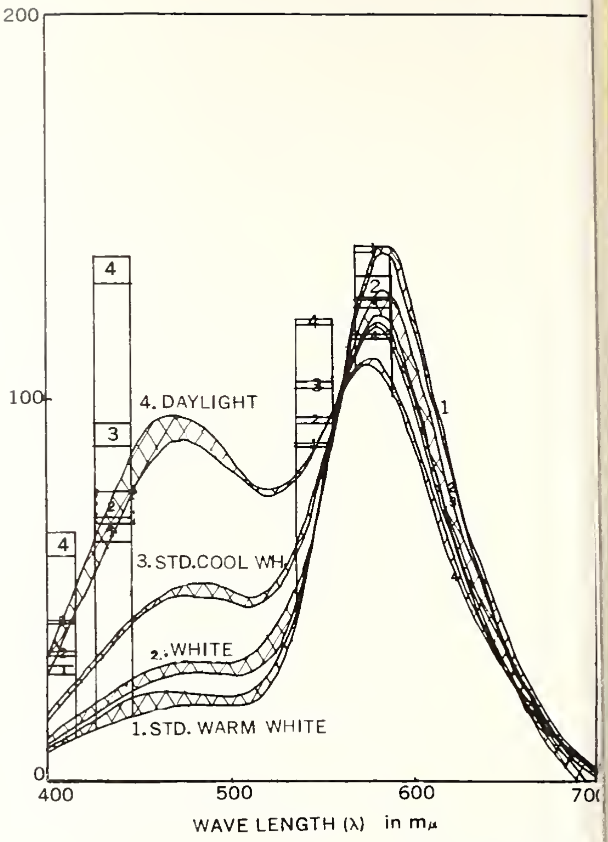

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Figure 2.—Relative spectral energy curves for four white fluorescent lamps in current production. Cross-hatched areas indicate the narrow range of spectral differences for lamps of different manufacturers in this series of high-lumen output lamps.

source as a replacement for variable natural daylight in grading and inspection.

The spectral quality of light sources has a marked effect on the viewing of colored objects. As light falls upon the surface of an object some of the light is absorbed and some of it is reflected. The reflected light determines which color the normal eye perceives. A curve which describes the light leaving an object has a different shape than the curve for the light source itself.

A red or orange surface reflects a higher percentage of light in the shorter and longer wavelength of the visible spectrum, and reflects very little at wavelengths in the middle range. The curve for such a reflecting surface describes the surface of the object viewed, not the light which is reflected from it. Spectrophotometric values from such a curve would tell the percentage of light reflected at each wavelength. An abundance of energy at a given wavelength in a light source, will generally result in a large amount of that wavelength in the light reflected from a given object. If there is no energy at a given wave-

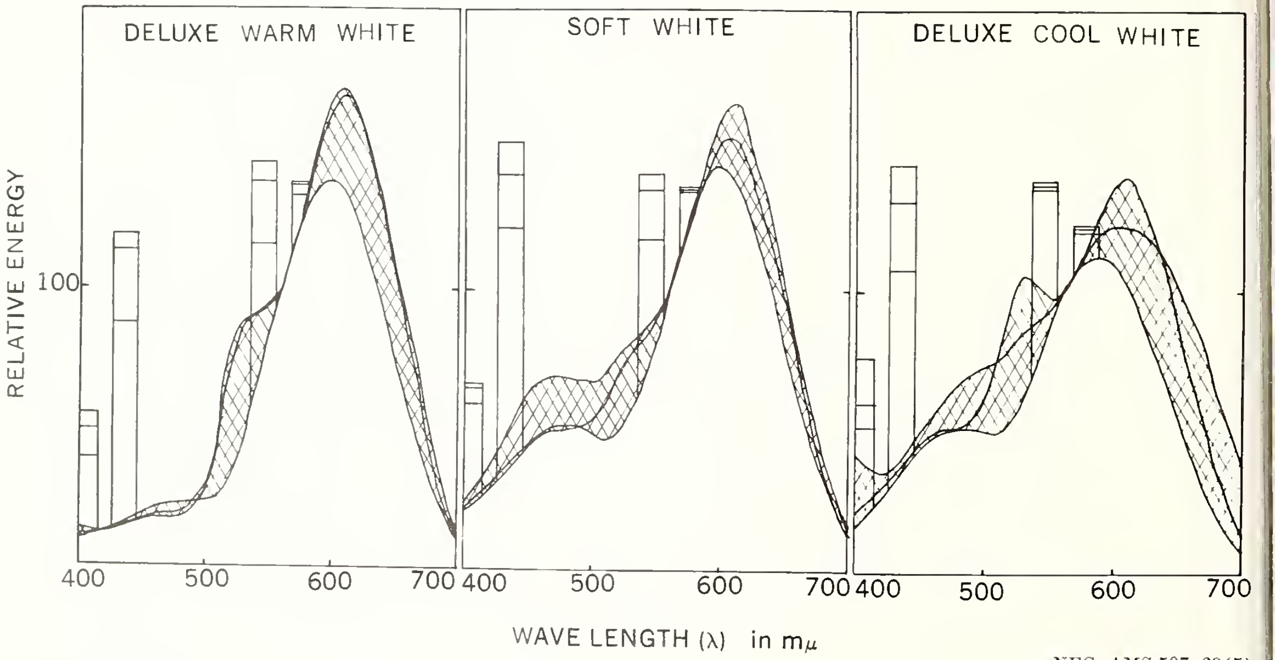

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Figure 3.—Relative spectral energy curves for deluxe cool-white fluorescent lamp designed to provide improved color rendition. Cross-hatched area indicates the wide range in spectral quality of lamps made by different manufacturers.

length in the light source, there will be none reflected, no matter what the percent of reflectance may be at that wavelength.

For these reasons, a study was started to ascertain the effect of various light sources, that are used today for the inspection of grain samples, and to determine which inexpensive light source most closely approximates natural daylight. The artificial north sky daylight lamp has been shown (*4, 5*) to provide comparable uniform distribution of energy through the visible spectrum. The light should neither accentuate nor diminish wavelengths of reflected light from objects viewed. The standard artificial north sky daylight lamp is big and unwieldy, and expensive. It would not be satisfactory for routine grain inspection. It was used in these tests as standard because it is the most acceptable and widely used standard today. However, a more portable and less expensive lamp is needed for grain inspection.

Ide and Burrows (*3*) described a series of tests using various artificial illuminants and Munsell repaints as control color standards upon which the present studies are patterned.

Trumbo, Adams, Milner, and Schipper (*7*) pointed out the need for conducting the studies presented here when they said: "While no significant relationship was found between intensity of illumination and magnitude of errors, the reliability and accuracy of inspection of Hard Red Winter wheat may be affected by other physical environmental factors such as quality of illumination and reflectance characteristics of the working surface."

MATERIALS AND METHODS

Four illuminants were selected for the tests:

No. 1 source 7,300° K., contained four 40-watt special fluorescent tubes (48 inches), and four 33-watt incandescent bulbs with diffusing glass, comparable to C.I.E. standard C in figure 1.

No. 2 source contained two 40-watt special fluorescent tubes, one 40-watt blue fluorescent tube and one 40-watt cool white fluorescent tube (all 48 inches), with diffusing plastic.

No. 3 source contained two 40-watt cool white fluorescent tubes (48 inches), comparable to spectral energy curve for cool white shown in figure 3.

No. 4 source contained two 40-watt daylight fluorescent tubes (48 inches), comparable to spectral energy curve for daylight shown in figure 2.

These test illuminants were each compared with the artificial north sky daylight standard, 7,500° K. This is a unit approximately 33 by 44 by 48 inches high, containing four 1,000-watt incandescent bulbs, each filtered with a Corning No. 5900 blue filter with diffusing glass. The spectral energy distribution curve for this lamp is comparable to the filtered incandescent curve shown in figure 1.

The series of colors chosen for this study represent the range of colors (table 1) in wheat and corn, which are important commodities in grain inspection.

Each 3-by-4-inch color was mounted on 3-by-5-inch heavy gray cardboard, so that the chip could be handled without touching the color surface.

A color board of heavy gray cardboard, 19½ by 26 inches, was overlaid with another cardboard of the same size, out of which four areas each 3 by 20 inches had been cut. Each area could contain four color cards, so that the 16 color cards representing a color series could be arranged in a 4-by-4 pattern.

The arrangement of color chips for series A is shown in figure 4. The chips of series B and C were similarly arranged on the panel. They are identified in table 1.

A workboard was prepared, similar in color and size but containing a measured grid rather than the color cards (figure 4).

The standard artificial north sky daylight source was supported on a table, so that the viewing surface was 36 inches from the floor. A booth was placed on either side of the standard illuminant. Test lamps were installed, as required, in booths (fig. 5) made of plywood. Each of the two booths was 6 feet high with the viewing surface 36 inches high. The test lamp was mounted in the upper portion of the booth in such a way that it could be raised or lowered. The front of the booth was open for 24 inches above the viewing surface.

TABLE 1.—*Arrangement of color chips from Munsell repaints* [1]

Series A (Colors of wheat)	Series B (Colors of wheat)	Series C (Colors of corn)
2.5 YR 5/2	2.5 YR 6/2	2.5 Y 8/4
/4	/4	/6
/6	/6	/8
/8	/8	/10
5.0 YR 5/2	5.0 YR 6/2	5.0 Y 8/4
/4	/4	/6
/6	/6	/8
/8	/8	/10
7.5 YR 5/2	7.5 YR 6/2	7.5 Y 8/4
/4	/4	/6
/6	/6	/8
/8	/8	/10
10 YR 5/2	10 YR 6/2	
/4	/4	
/6	/6	
/8	/8	

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[1] Munsell Book of Color, 1950, Munsell Color Company, Baltimore, Md. The yellow-red (YR) and yellow (Y) colors are identified in the Munsell notation in this table.

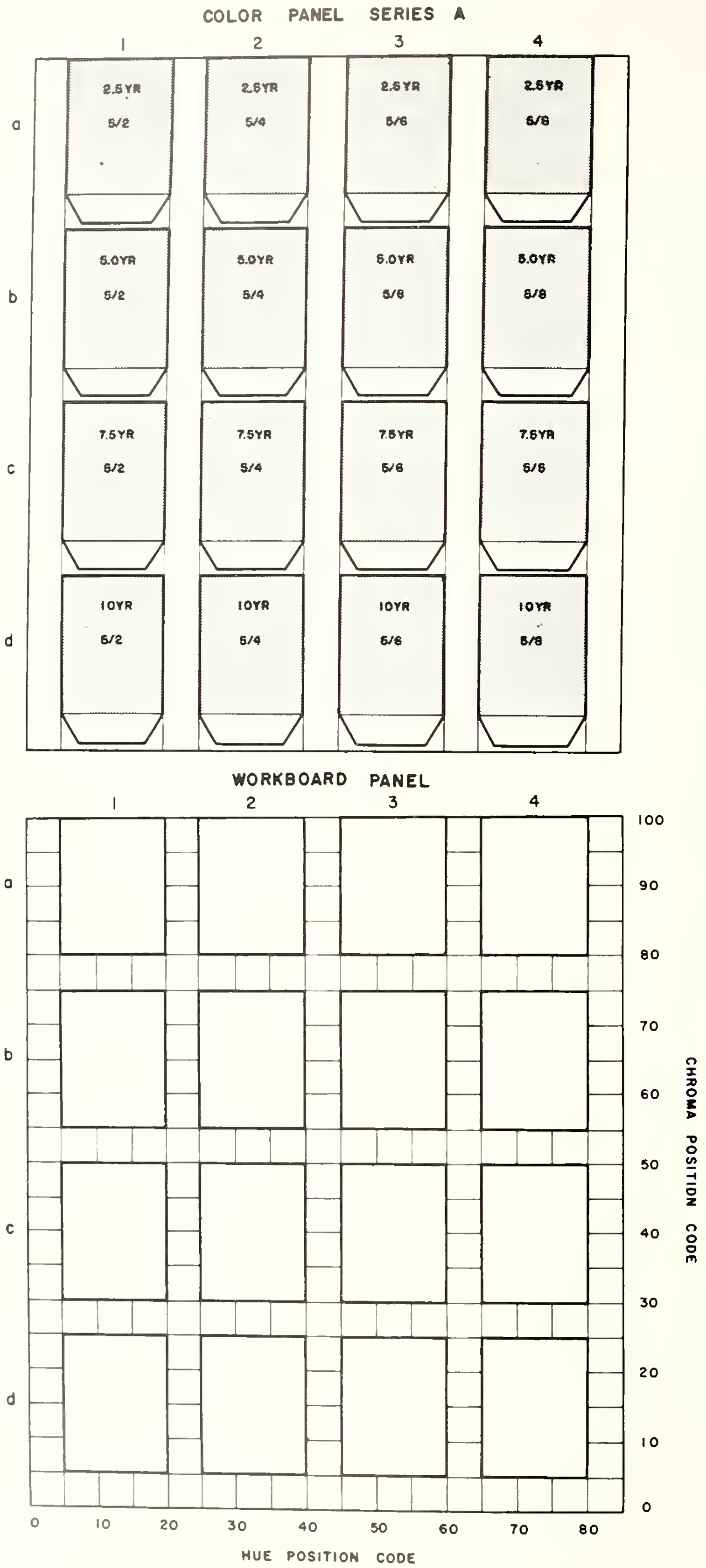
COLOR PANEL SERIES A
1
2
3
4
a
b
c
d
2.5YR 5/2
2.5YR 5/4
2.5YR 5/6
2.5YR 5/8
5.0YR 5/2
5.0YR 5/4
5.0YR 5/6
5.0YR 5/8
7.5YR 5/2
7.5YR 5/4
7.5YR 5/6
7.5YR 5/8
10YR 5/2
10YR 5/4
10YR 5/6
10YR 5/8
WORKBOARD PANEL
1
2
3
4
a
b
c
d
100
90
80
70
60
50
40
30
20
10
0
CHROMA POSITION CODE
0
10
20
30
40
50
60
70
80
HUE POSITION CODE

Figure 4

LIGHT COMPARISON CHAMBER

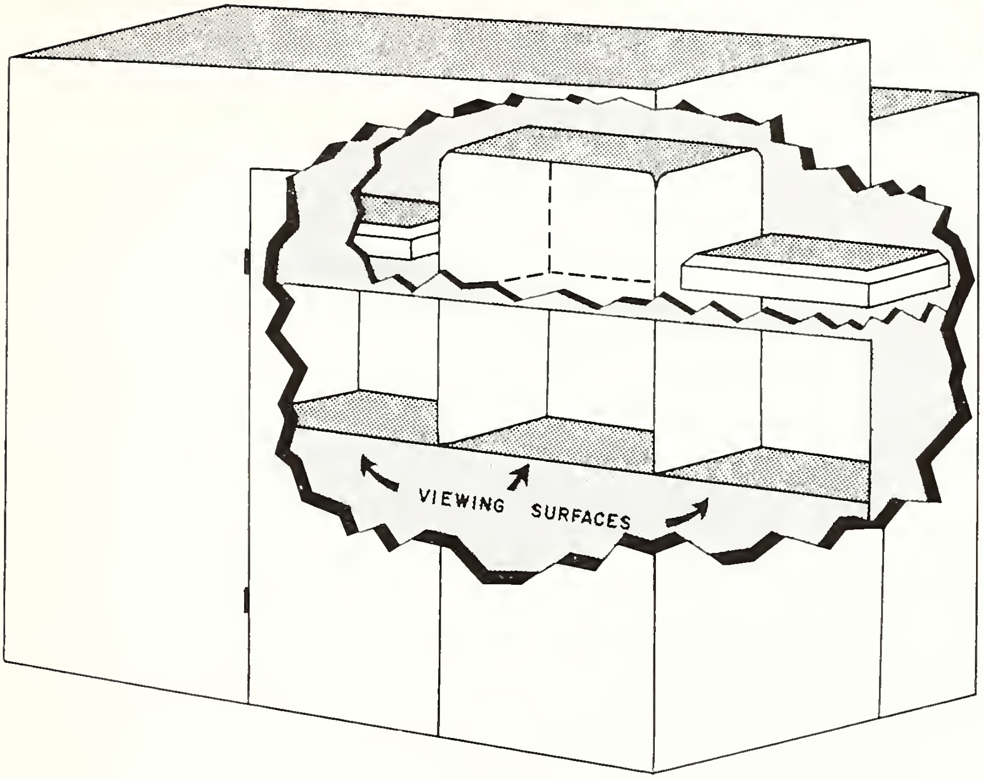

FIGURE 5

A chamber (fig. 5) constructed of plywood 4 feet wide, 8 feet high and about 13 feet long was placed immediately in front of the three light booths. Three areas were cut out of the back wall of this chamber so that an individual standing in the chamber was able to observe materials placed on the viewing surface of any one or all of the structures. There was a door in the front of the chamber, and an exhaust fan and intake filter (not shown in fig. 5) provided ventilation. All interior surfaces of the chamber and of the booths were painted a neutral gray, Munsell N 6.5/.

EXPERIMENTAL PROCEDURE

In preparing for a test by either of the following procedures, the standard lamp and all test lamps were adjusted in the light booths to provide both 130 foot-candles of light at the viewing surface and a standard condition of viewing at a 45° angle.

Two kinds of experiments were conducted: A panel test with determination of error of estimate, and a background color test.

Panel Test

To conduct a panel test, a color board containing chips of series A, arranged as shown in figure 4, was placed on the viewing surface of the standard illuminant. Arrangement of color chips of series B and C is shown in table 1. The workboard containing the measured grid was placed on the viewing surface below one of the four test illuminants.

The operator stood at the juncture of the two booths. The person conducting the test furnished individual color chips of the appropriate series to the panelist. The panelist placed each chip in the location on the workboard panel where he thought the color belonged, so as to give an exact match to a corresponding color chip on the panel under the standard illuminant. If he thought a chip was not an exact match, he was instructed to place the color chip on the workboard in the position most nearly corresponding. The location of each chip on the workboard panel was recorded by the person conducting the test and the chip removed before the panelist was presented with another chip. A complete test consisted of the panelist having been presented with all color chips comprising the series in random order and on two occasions.

Operator's Error of Estimate

All operators were given color aptitude tests before their participation in this study to determine that they had normal color vision. Six operators comprised the "repeat" group. These six individuals repeated all tests twice and also participated in a study to determine their error of estimate. For this test, a panel was inserted vertically at the center of the viewing surface of the north sky daylight standard. This divided the viewing area into two smaller areas. The panelists were not aware either that the light was from the standard north sky daylight or that the two viewing surfaces were lighted by the same source. They were shown pairs of color chips, one on each viewing surface. They were asked to indicate whether the two chips were: An exact match, very close, close, fairly close, different, or very different.

Background Color Study

The second major test procedure was the background color study. Samples of grain were prepared by the Chicago Board of Appeals and Review of the Grain Division, AMS. These samples were presented to panelists who made their own separation of the grain on the various background colors under test. All operators participating in this study were experienced in grading grain. Background colors were applied to fiberboard panels, upon which the sample was placed. A panel of the same size was covered with the buff-colored plastic material used as standard background in grain offices. Separations made on this background were used as the standard for comparison with the separations made on test backgrounds.

RESULTS

Panel Test—Repeat Group

Six operators formed the repeat group for the panel test study. These operators examined color chips of all series in replicate, and duplicated the entire procedure on two occasions. Care was taken to prevent operator fatigue, although all panel operators were allowed as much time as they wished to match colors. The placement of each color chip in relation to its correct hue and chroma position measured the ability of the operator to identify correctly the color under that illuminant (or test light source).

All data from this repeat group were coded for computer analysis using the methods described in Snedecor (*9*). Based on approximately 4,500 observations, test lamp #1 is apparently the most accurate source of artificial light for the test colors (table 3, appendix). Results of the panel test for the repeat group are expressed in the table as the mean and the standard deviation or confidence limits about zero (the correct hue or chroma position) of the 24 observations of each card examined under each of the test lamps.

Table 2 shows the number of cards in each series which the operators were unable to identify accurately, as indicated by significant departures from correct position. A significant departure from correct position is measured by a standard deviation greater than that expected at the 0.01 level. Series A and B contained 16 cards each, series C, 12 cards. Light source #1 proved to be by far the best illuminant for distinguishing colors.

Standard deviations that are significant at the 0.01 level are marked with an asterisk in table 2. Significant standard deviations indicate failure of the operators to properly position the color chips, and so are a measure of the failure of the light source to render color accurately. Table 2 in the appendix reveals a striking advantage in accuracy for test lamp #1.

The advantage of test lamp #1 in judging chroma properly was not quite as great as in the judgments for hue identification, but the results still indicate test lamp #1 to be best for this purpose. The data for services B and C further support the choice of test lamp #1 as the best light

Table 2.—*Statistically significant number of cards that are incorrectly identified under four test lamps*

Test light number	Cards with hue incorrectly identified in—			Cards with chroma incorrectly identified in—		
	Series A (16 cards)	Series B (16 cards)	Series C (12 cards)	Series A (16 cards)	Series B (16 cards)	Series C (12 cards)
	Number	*Number*	*Number*	*Number*	*Number*	*Number*
1	4	2	0	3	0	2
2	13	13	3	7	9	8
3	11	10	4	12	10	8
4	14	13	7	4	2	4

source. Colors in the C series seemed to be more difficult to identify for chroma than for hue, in contrast to the greater difficulty encountered with proper hue identification in color series A and B.

Determination of Operator's Error of Estimate

To provide information on the operator's error, caused by factors other than the light source, an operator's error of estimate test was conducted. The manner in which this test was conducted was described in the experimental procedure section.

The nine color cards of primary interest in this test are those cards which panelists failed to place accurately under the best test illuminant (#1). They are cards 10, 34, 08, 36, and 38 from series A: 01 and 21 from series B: and 09 and 23 from series C.

Operators were presented pairs of cards, one card on each of the two viewing surfaces. The illuminant standard north sky daylight and its intensity were the same for the two viewing surfaces, although the operators were not aware that this was the case. The operators rated each pair of cards in one of the six categories ranging from an "exact match" to "very different."

Examination of data from this test showed that the operators rated the "degree of match" correctly. On the basis of this test, operator's error of estimate was eliminated as a factor in examining data on the panel test previously described and in subsequent tests. The panel test, as described earlier, was repeated under identical conditions of illumination for the color panel series and workboard panel. These data also showed that panelists could match colors correctly if illumination on the two viewing surfaces was the same.

Panel Test—Variable Group

Preceding data confirm the methodology employed in the following illuminant study. To gain more information concerning the ability of individuals to identify colors of the series, an additional group of operators participated in the study. This group consisted of 11 licensed grain inspectors and 1 seed laboratory scientist. These 12 operators functioned in the panel test in the same manner as the repeat group, with the exception that they were required to replicate comparisons, but not duplicate the test. However, not all of the operators were able to replicate comparisons for all color chips of all series.

A primary purpose in having these individuals participate was that they all perform daily examinations of grain as a part of their duties. These inspectors are among the most skilled individuals within the grain inspection service in the United States, and have some responsibility for maintaining the specified conditions under which grain inspections are made.

Graphic presentation of the data from tests by these operators, plus the data accumulated by the repeat group are presented in the following scatter diagrams (figs. 6 through 13. Figs. 12 and 13 are on the center spread, pp. 12 and 13). Each of the rectangular areas depicted on these graphs records the ability of each operator to place the card correctly at zero (indicated by the number in the upper-left-hand corner) for hue and chroma. Shifts in hue from the point of intercept are expressed by vertical movement above or below the horizontal line at the center of the diagram. Similarly, shift in chroma was recorded as placement of the point to the left or to the right of the line dividing it vertically. Such a shift measured failure to place the card correctly for hue and chroma. A dot where the horizontal line intersects the vertical line indicates that operators placed the card correctly for both hue and chroma. A departure of 25 units from the intercept on the hue scale in either direction indicates that the operators evaluated the color as one full hue step greater or less than its actual value. Horizontal shifts indicate that the operators considered the card to be of greater than correct intensity, if the shift is to the right, or less than correct intensity, if the shift is to the left. From 30 to 50 observations are recorded on each card.

The cards in each half of the figures are arranged in the same manner as the color chips on the color board presented to the operators. The notation A1 (figure 6) indicates color cards of series A tested under illuminant #1. Similarly, A2, 3, and 4 indicate color card series A tested with lamps 2, 3, and 4. Figures 8 and 9 present data for series B, and figures 10 and 11 present data for series C.

The figures illustrate graphically the superiority of test illuminant #1, as compared to illuminant 2, 3, 4. In color series A, operators generally tended to underestimate hue and overestimate chroma under lamps 2, 3, and 4. Figures 8 and 9 show a similar trend in colors in the B series, although, with perhaps a closer estimation for colors of this series under test illuminant #1 than in series A. Data from the C series follows a similar pattern, except that shifts for accuracy of chroma ratings seem to be more common than for hue ratings.

Data for the placing of each card may be examined separately. Vertical shifting of the card in excess of 25 units, from either the horizontal or vertical, indicated that the operator confused it with the card immediately above or below, depending on the direction of the shift.

Data from individual cards from series A may be examined in detail in figures 12 and 13 (pp. 12 and 13, center spread), which show the data for four cards under each of the four test illuminants. These figures show actual examples of some of the colors that were used in the tests. In figure 12, value and chroma levels do not change: the colors

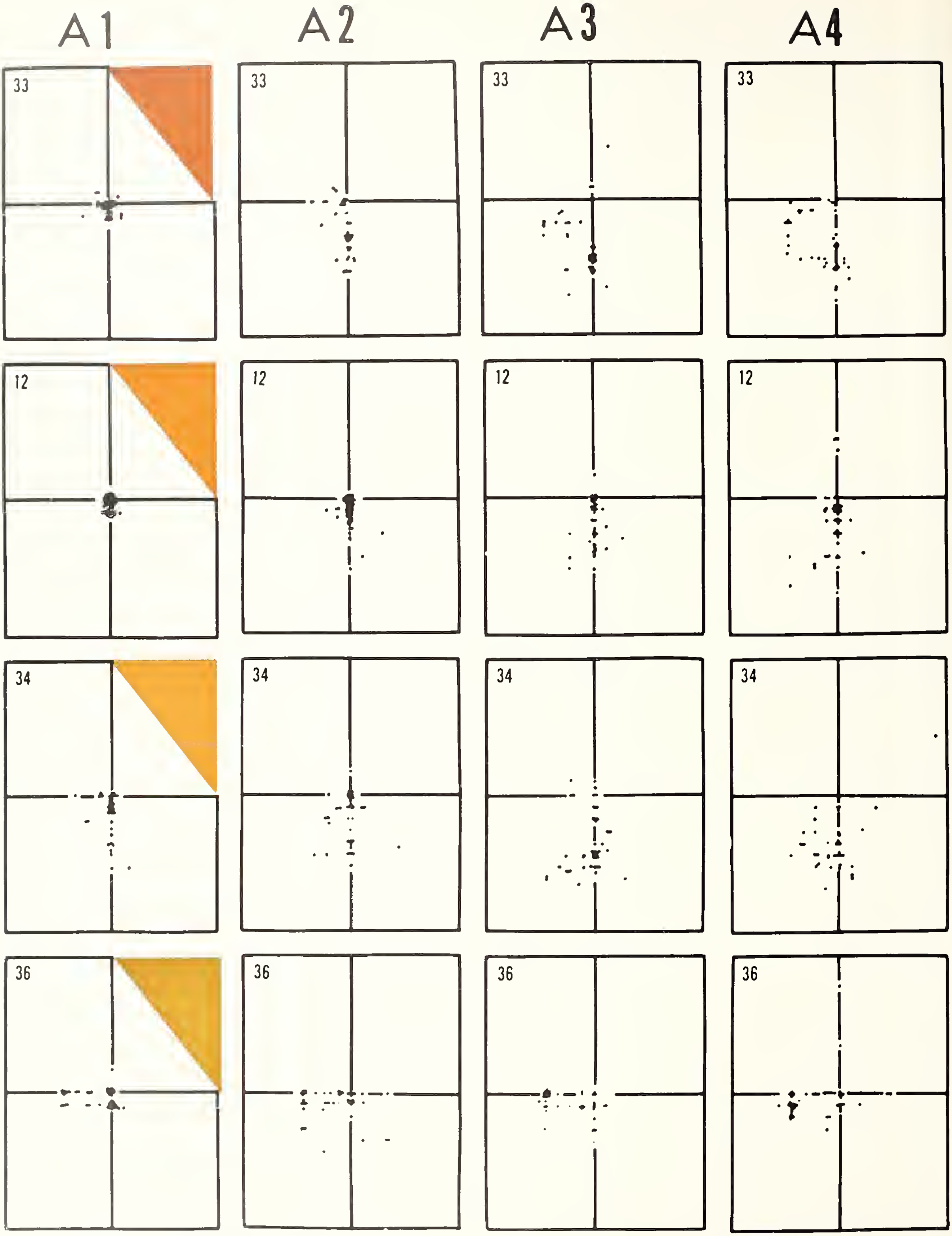

Figure 12.—Scatter diagrams of panelists' ability to identify hue and chroma of color chips 33, 12, 34, and 36 of series A when tested under four test illuminants.

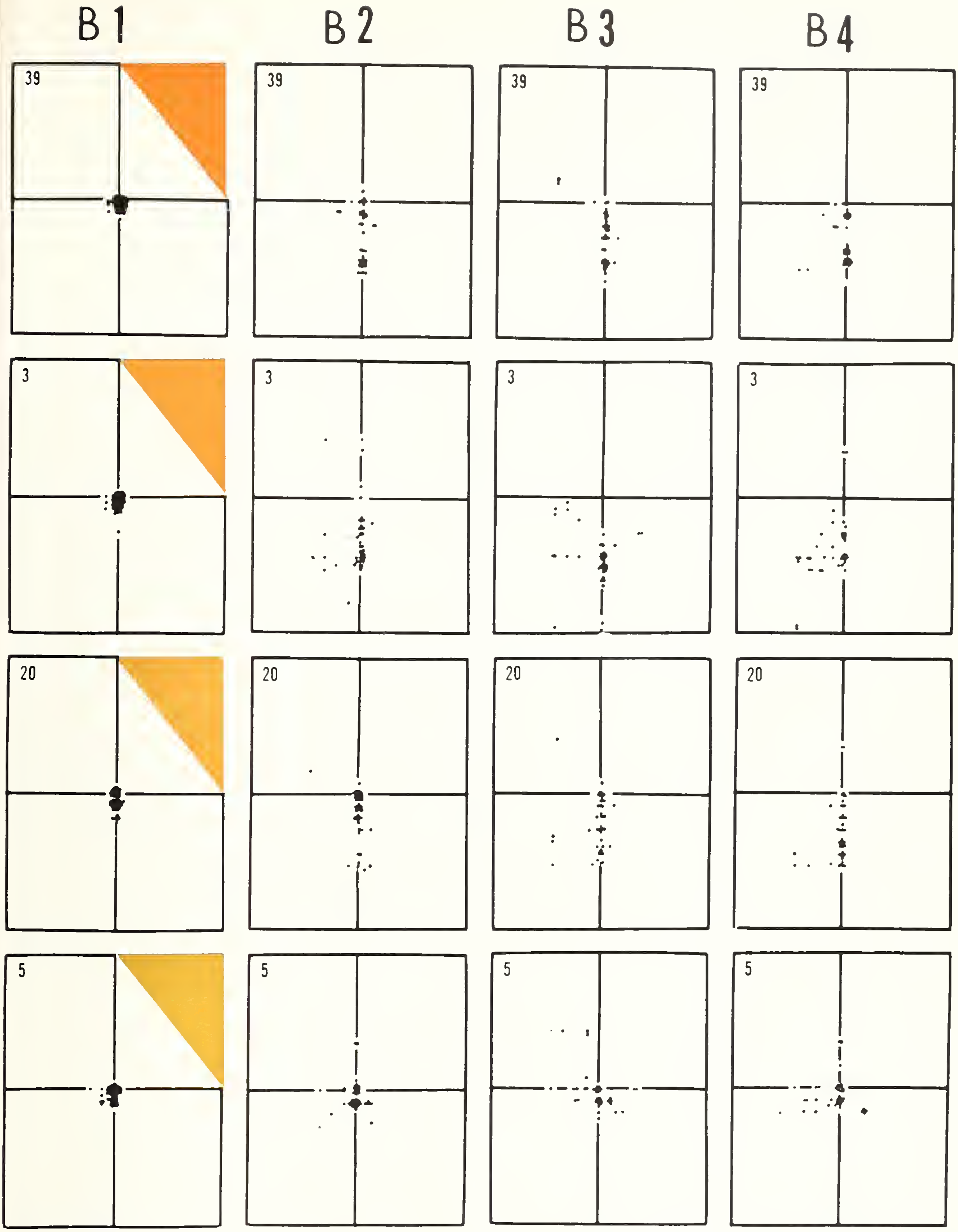

Figure 13.—Scatter diagrams of panelists' ability to identify hue and chroma of color chips, 39, 3, 20, and 5 of series B when tested under four test illuminants.

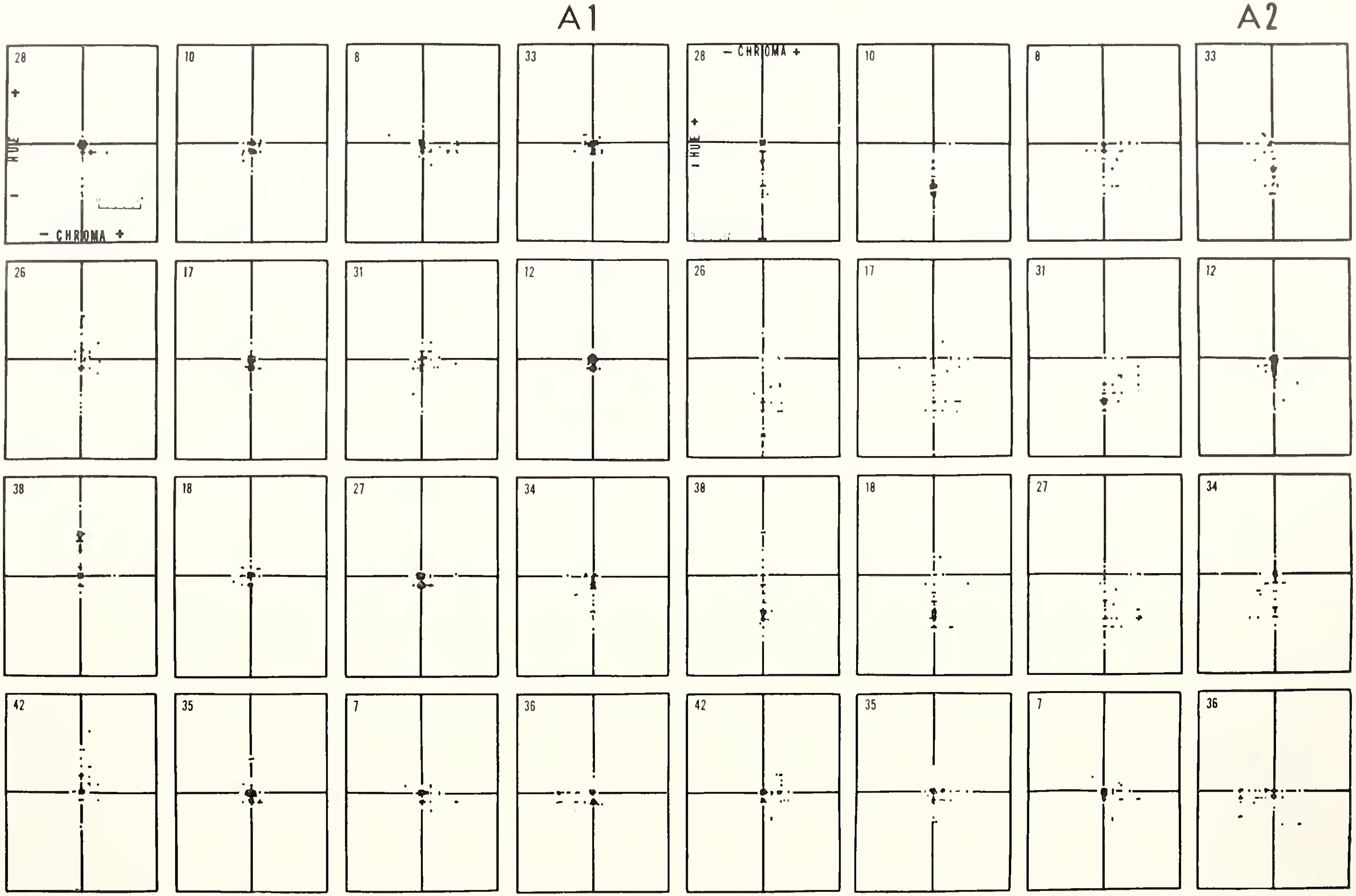

FIGURE 6.—Scatter diagrams of deviations by panelists from correct placement (0) of cards in color series A, under test illuminants 1 and 2.

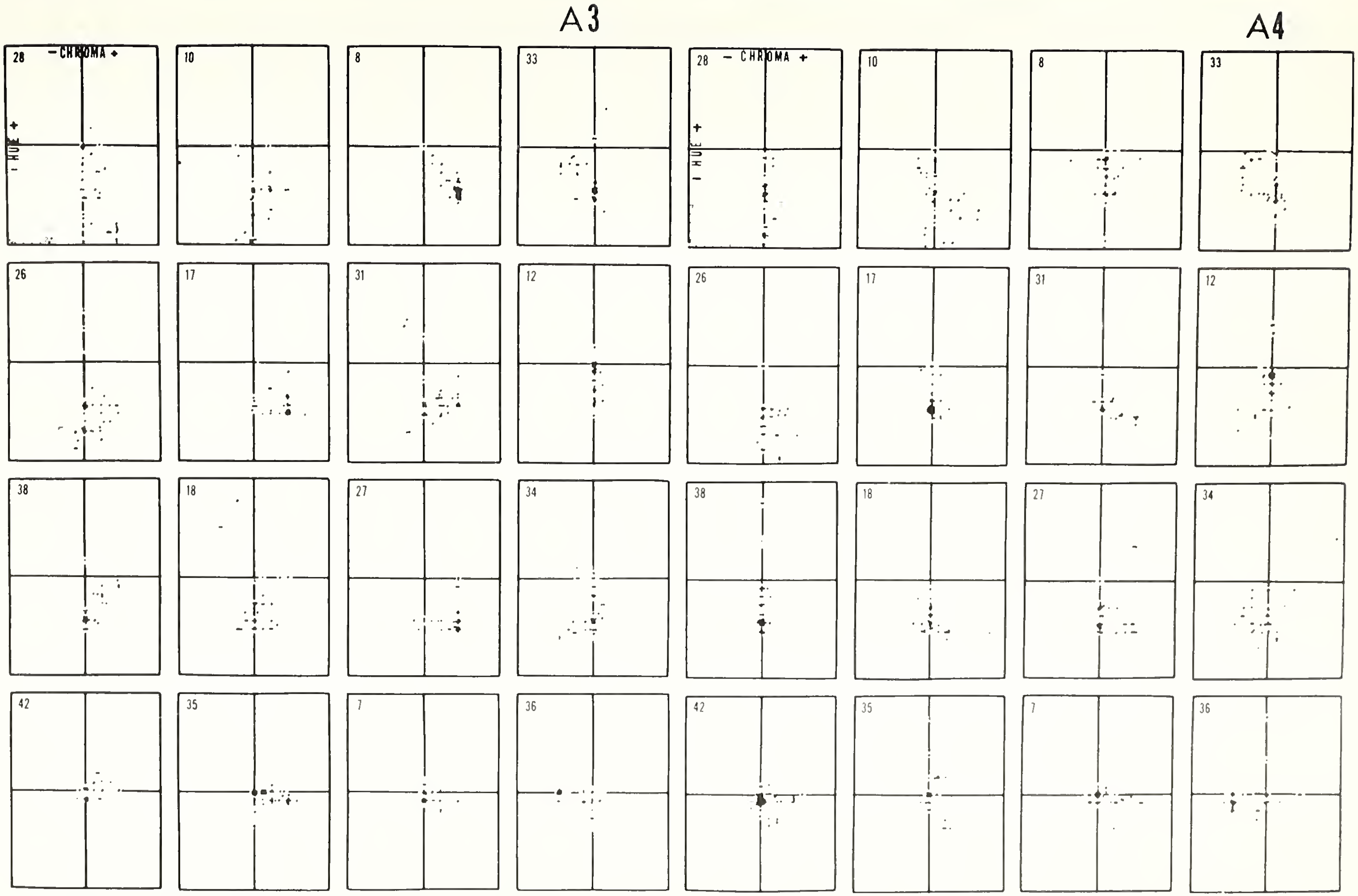

FIGURE 7.—Scatter diagrams of deviations by panelists from correct placement (0) of cards in color series A, under test illuminants 3 and 4.

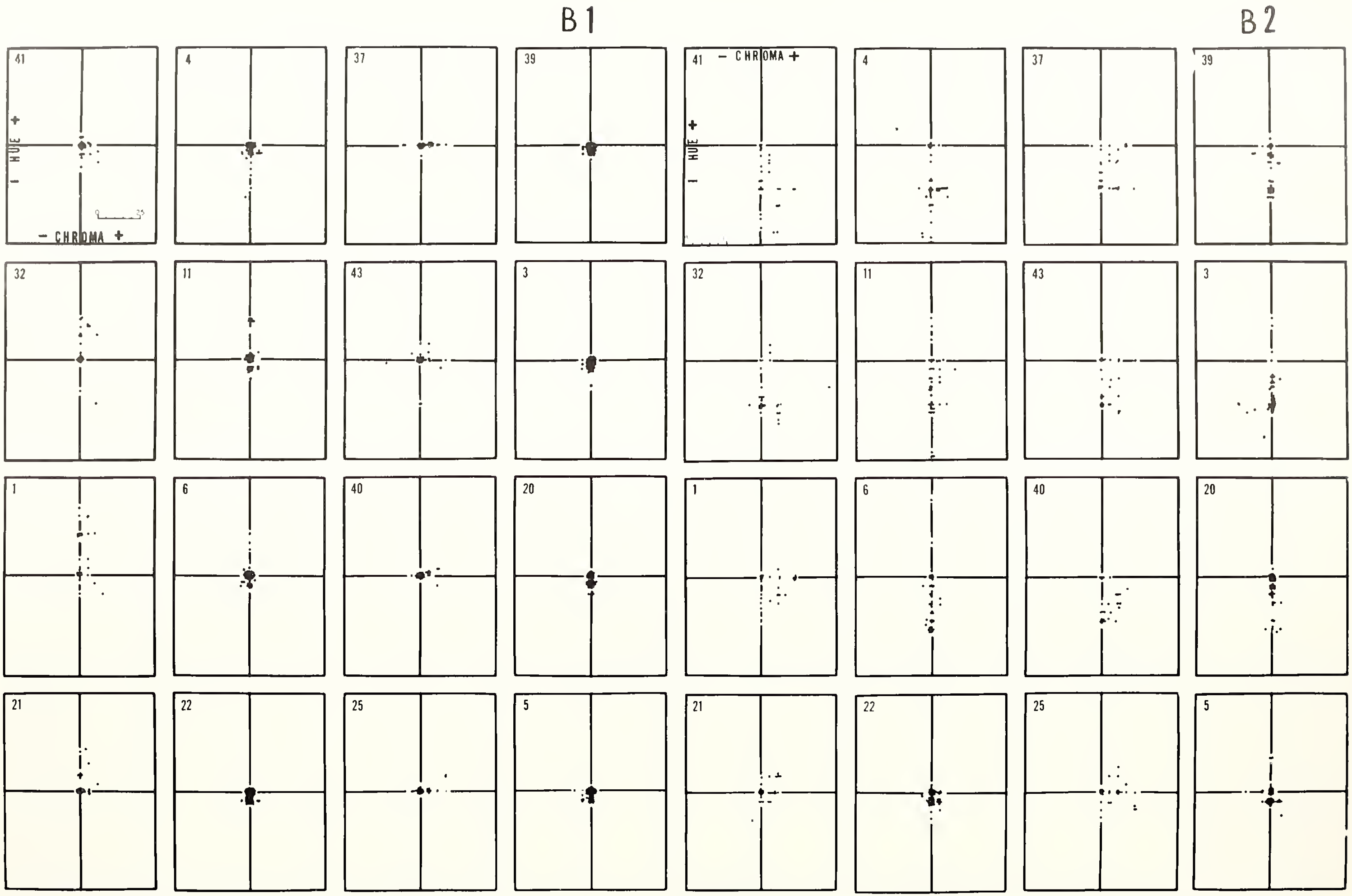

FIGURE 8.—Scatter diagrams of deviations by panelists from correct placement (0) of cards in color series B, under test illuminants 1 and 2.

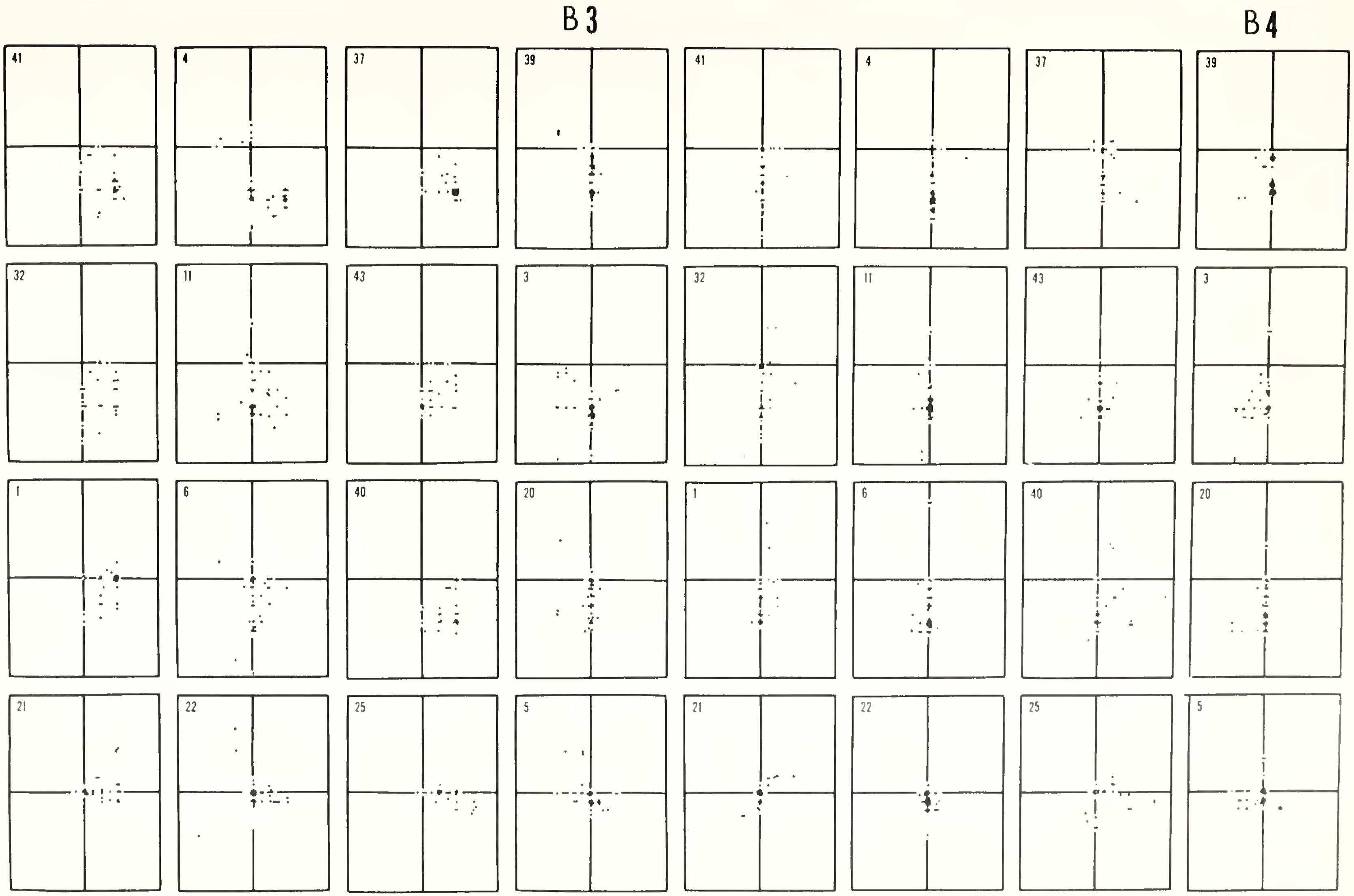

FIGURE 9.—Scatter diagrams of deviations by panelists from correct placement (0) of cards in color series B, under test illuminants 3 and 4.

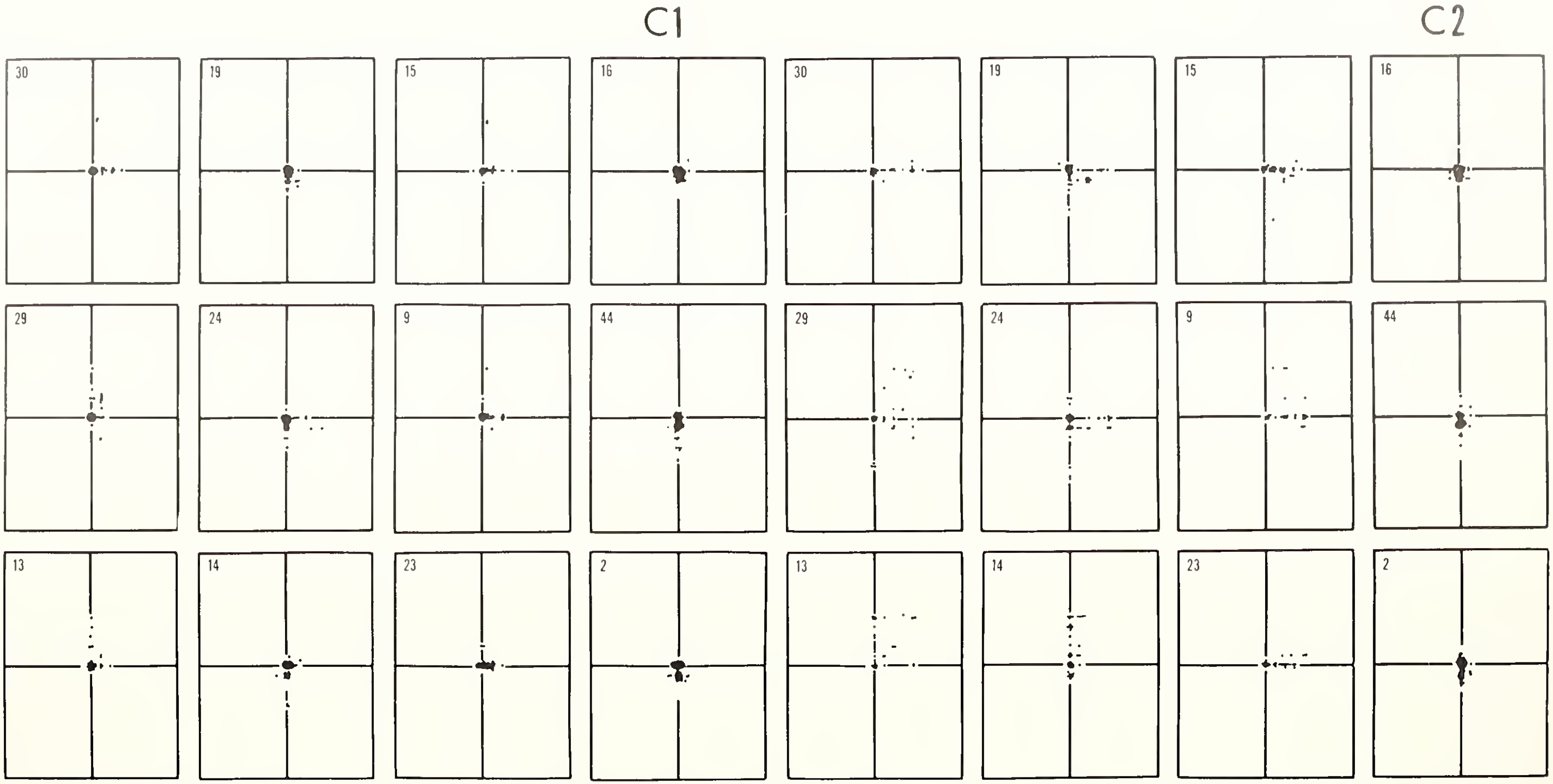

Figure 10.—Scatter diagrams of deviations by panelists from correct placement (0) of cards in color series C, under test illuminants 1 and 2.

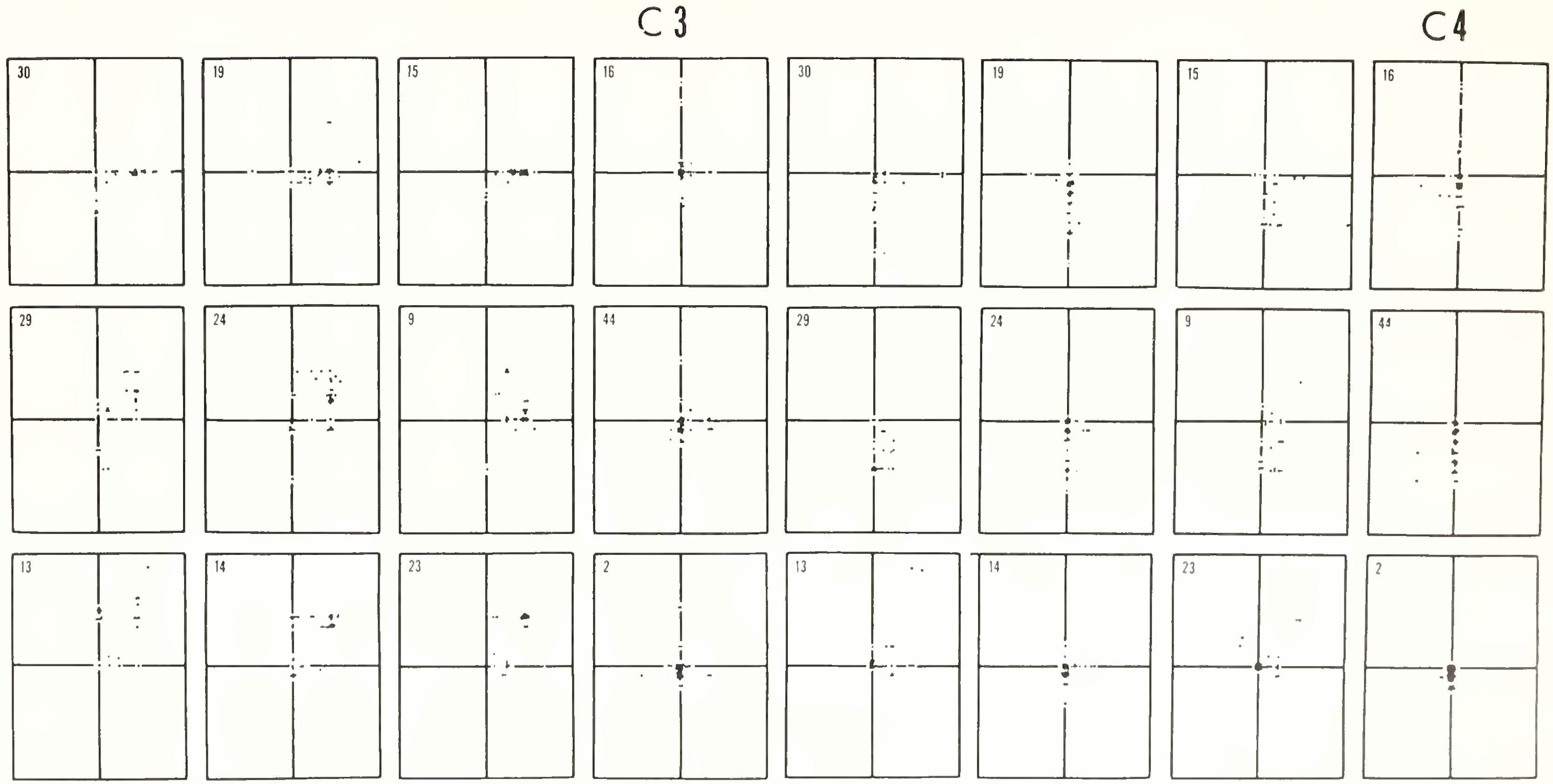

FIGURE 11.—Scatter diagrams of deviations by panelists from correct placement (0) of cards in color series C, under test illuminants 3 and 4.

vary, only in hue, from top to bottom. In the B series, in figure 13, the hue and chroma are the same, but the colors vary from those in figure 12 only in lightness (or value). Figure 12 illustrates four colors of the A series; figure 13, four colors of the B series.

BACKGROUND COLOR STUDY

The experimental procedure for the background color study has been presented in the section, "Materials and Methods." Fifteen background colors, applied to fiberboard backgrounds, were used in the preliminary study. The background colors included black, gray, brown, yellow, red, green, and blue. One board covered with the buff-colored plastic material now used in grain inspection offices served as standard. Samples of these types of wheat were used:

Laboratory number	*Subclass—Variety*
44927	Hard White
361–519	Soft White
45851	Hard Amber Durum
161–373	Durum
261–39	Red Winter
361–494	Yellow Hard Winter
261–445	Dark Hard Winter
361–578	Dark Northern Spring
261–408	Dark Northern Spring
	Dark Hard Winter—Red Chief
361–550	Dark Northern Spring—Spinkcota*

*Spinkcota contained 90% dark, hard, and vitreous kernels, tested 18 percent protein, and 58 for sedimentation. The kernels are bleached, making grading for subclass difficult.

Individuals participating in the test were all experienced in grain inspection. The Chicago Board of Appeals and Reviews of the Grain Division had indicated the constitution of all samples; their specifications served as the standards for the test. Operators were asked to examine samples on each of the background colors. All examinations were made under artificial north sky daylight illumination. Components separated were weighed by the individual conducting the test, and the results recorded. In addition, each inspector was asked to indicate his reaction to each of the test backgrounds. Analysis of the data and the remarks of the operators indicated that the data were confused with board texture and gloss, so that color was not the only factor which affected results. This was particularly serious because the panels varied in texture and gloss from color to color. However, the data did demonstrate that inspectors could grade samples of wheat more accurately on pastel colors complementary to the wheat color than on backgrounds of the same color range.

Late in the study, backgrounds were prepared by "back painting" frosted translucent 4-mil mylar plastic with colors (light green and blue) complementary to the color of wheat. In addition, backgrounds were prepared that closely matched the buff plastic material now used by grain inspection offices. Preliminary tests indicate that with this material, study of the effects of color on grain grading can be made without the effects of gloss and texture. Because the color is applied to the back of the plastic material, the texture and surface gloss for all test panels are identical. The mylar was mounted on fiberboards to provide a flat, firm surface for grain handling. Another advantage of this surface is that cleaning does not affect the color.

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APPENDIX

Table 3.—*Mean and standard deviation of panelists of the repeat group in identifying the hue and chroma of cards on work boards of the color series A, B, and C, when examined under four test illuminants*

[Color board of chips lighted by Standard Artificial North Sky Daylight]

Series	Card number	Light number	Hue		Chroma	
			Mean	Standard deviation	Mean	Standard deviation
A	07	1	−0.042	±1.176	0.333	±1.879
		2	.333	±1.968	1.208	±3.156
		3	−.333	±2.308	3.583	±3.900
		4	−.625	±1.339	1.000	±2.892
	08	1	−1.125	±2.029	6.708	*±4.883
		2	−6.042	*±4.996	4.333	±4.417
		3	−21.375	*±5.158	17.208	*±3.362
		4	−13.792	*±5.465	.375	±1.887
	10	1	−2.708	*±2.238	−.917	±1.392
		2	−21.250	*±3.430	−.042	±.117
		3	−23.292	*±5.560	4.958	*±4.647
		4	−22.625	*±9.424	−1.375	±2.949

*Significant at the .01 level.

—Continued

Table 3.—*Mean and standard deviation of panelists of the repeat group in identifying the hue and chroma of cards on work boards of the color series A, B, and C, when examined under four test illuminants*—Con.

Series	Card number	Light number	Hue		Chroma	
			Mean	Standard deviation	Mean	Standard deviation
A	12	1	−.750	±1.137	−.125	±.351
		2	−3.667	*±2.434	−1.042	±1.458
		3	−8.833	*±6.238	−1.250	±1.935
		4	−8.833	*±4.792	−2.125	±2.651
	17	1	1.958	±4.430	−.167	±.920
		2	−10.500	*±6.475	4.542	±5.059
		3	−19.625	*±5.528	12.117	*±4.968
		4	−21.125	*±3.380	.333	±.856
	18	1	1.375	±1.940	−.167	±1.517
		2	−13.833	*±6.516	−.125	±1.561
		3	−5.917	±13.148	−.708	±5.522
		4	−18.625	*±4.702	−1.750	±2.704
	26	1	3.792	±8.139	1.125	±1.987
		2	−25.583	*±9.033	2.667	*±2.555
		3	−24.042	*±10.435	5.542	*±4.415
		4	−29.583	*±6.860	2.125	±2.502
	27	1	−1.167	±1.316	1.917	±2.500
		2	−17.917	*±6.372	10.417	*±5.121
		3	−20.000	*±5.068	13.583	*±6.866
		4	−21.167	*±4.209	4.500	±4.760
	28	1	−2.375	±3.708	1.125	±1.301
		2	−12.000	*±6.957	0.0	±0.0
		3	−21.792	*±11.083	3.833	*±3.819
		4	−32.750	*±8.122	.416	±.809
	31	1	−1.000	±4.890	.583	±1.763
		2	−17.000	*±6.282	3.583	±3.604
		3	−18.625	*±7.456	9.917	*±5.323
		4	−19.708	*±6.699	−.250	±3.573
	33	1	−.167	±1.469	−1.417	±1.763
		2	−9.250	*±5.038	−3.292	*±2.957
		3	−17.208	*±5.339	−5.042	*±4.201
		4	−12.875	*±6.673	−9.000	*±4.870
	34	1	−5.750	*±4.278	−1.875	±2.361
		2	−7.958	*±5.447	−.875	±2.008
		3	−16.083	*±7.239	−2.708	±3.939
		4	−20.250	*±4.923	−5.042	*±4.229
	35	1	−.750	±1.137	.750	±1.137
		2	−.833	±1.090	2.958	*±2.537
		3	−.667	±1.226	8.583	*±6.446
		4	−2.208	*±2.096	1.333	±1.761
	36	1	−1.042	±1.458	−6.625	*±4.697
		2	−4.333	*±4.096	−7.125	*±6.533
		3	−2.500	±2.671	−10.000	*±5.603
		4	−3.417	*±2.551	−12.333	*±6.190
	38	1	10.708	*±8.560	2.083	±5.847
		2	−5.458	±9.594	1.500	±3.860
		3	−19.667	*±4.675	2.792	±2.956
		4	−12.750	*±8.429	.417	±.809
	42	1	8.250	*±5.570	.708	±1.487
		2	1.167	±2.434	3.667	*±2.840
		3	−.083	±2.734	7.125	*±6.626
		4	6.667	±7.099	.708	±2.113
B	01	1	10.917	*±8.156	2.000	±2.196
		2	−5.542	±5.661	6.583	*±4.415
		3	−4.167	±5.154	13.042	*±5.081
		4	−9.333	*±8.529	1.500	±2.048

*Significant at the .01 level.

—Continued

TABLE 3.—*Mean and standard deviation of panelists of the repeat group in identifying the hue and chroma of cards on work boards of the color series A, B, and C, when examined under four test illuminants*—Con.

Series	Card number	Light number	Hue		Chroma	
			Mean	Standard deviation	Mean	Standard deviation
B	03	1	.417	±2.176	.117	±.809
		2	−15.292	*±6.915	3.167	±3.653
		3	−24.292	*±3.865	−.158	±3.955
		4	−20.333	*±4.650	5.833	*±4.195
	04	1	−2.125	±2.428	.333	±1.237
		2	−16.458	*±7.339	2.125	*±1.876
		3	−26.542	*±6.571	9.292	*±5.338
		4	−26.500	*±4.663	.208	±.585
	05	1	−.750	±1.137	−1.042	±1.458
		2	−2.250	*±2.064	−.512	±2.365
		3	−1.917	±2.062	3.000	±9.272
		4	−3.125	*±2.995	−.500	±6.898
	06	1	1.667	±3.432	−.125	±.351
		2	−9.292	*±7.122	−.125	±.639
		3	−8.917	*±6.388	2.333	±2.549
		4	−16.833	*±7.388	−1.042	±1.458
	11	1	2.958	±4.851	.500	±1.055
		2	−11.167	*±7.109	1.667	±2.101
		3	−10.000	±10.579	4.417	*±3.885
		4	−23.958	*±1.702	−.625	±1.284
	20	1	−1.917	±2.163	−.042	±.117
		2	−5.125	*±4.312	0.0	±0.0
		3	−10.375	*±5.371	−.667	±2.549
		4	−15.958	*±5.527	−1.042	±2.386
	21	1	5.500	*±4.799	2.083	±2.150
		2	.208	±3.417	2.512	*±2.528
		3	2.542	±4.524	9.583	*±4.772
		4	.458	±3.845	1.333	±3.374
	22	1	−1.042	±1.188	.125	±1.059
		2	−1.500	*±1.251	1.667	*±1.380
		3	−2.000	±3.147	2.833	±5.236
		4	−4.833	*±3.634	.833	±1.090
	25	1	.875	±1.533	2.833	±3.086
		2	−1.208	±3.969	6.792	*±4.287
		3	−1.958	±2.609	15.208	*±5.487
		4	−2.792	±5.232	5.208	*±4.530
	32	1	4.458	±8.333	1.792	±2.273
		2	−17.833	*±7.147	4.167	±5.095
		3	−18.375	*±7.291	10.000	*±5.226
		4	−11.375	*±9.196	1.958	±2.553
	37	1	−.083	±.954	1.458	±2.974
		2	−14.292	*±5.708	4.208	*±3.643
		3	−22.958	*±2.581	16.250	*±3.805
		4	−14.042	*±6.596	2.167	±3.582
	39	1	−.958	±1.062	−.208	±.585
		2	−12.167	*±6.227	−1.083	±1.680
		3	−16.792	*±5.180	.375	±.733
		4	−19.208	*±6.700	−.625	±9.676
	40	1	0.0	±.862	.083	±2.048
		2	−15.500	*±5.679	3.458	*±3.306
		3	−17.333	*±5.683	14.958	*±3.668
		4	−16.792	*±7.962	2.125	±6.576
	41	1	−1.042	±1.839	1.458	±3.064
		2	−20.458	*±8.252	4.000	*±3.608
		3	−19.667	*±6.551	15.042	*±4.637
		4	−15.167	*±7.299	1.417	±2.266

*Significant at the .01 level.

—Continued

Table 3.—*Mean and standard deviation of panelists of the repeat group in identifying the hue and chroma of cards on work boards of the color series A, B, and C, when examined under four test illuminants*—Con.

Series	Card number	Light number	Hue		Chroma	
			Mean	Standard deviation	Mean	Standard deviation
B	43	1	−.625	±3.708	−.167	±3.221
		2	−13.917	*±6.586	2.500	*±2.209
		3	−15.292	*±6.977	7.333	*±4.628
		4	−15.958	*±7.758	.375	±3.445
C	02	1	−.958	±1.292	−.250	±.960
		2	−.500	±1.992	.208	±.585
		3	2.083	±5.534	1.250	±2.767
		4	−2.917	*±2.222	−.417	±.809
	09	1	.750	±3.601	2.333	*±1.960
		2	3.500	±5.113	11.625	*±4.316
		3	2.625	±6.606	14.792	*±3.604
		4	−7.542	±7.736	4.708	*±4.112
	13	1	2.792	±3.568	.833	±1.090
		2	13.708	*±7.669	4.167	*±3.932
		3	24.792	*±8.307	11.708	*±5.617
		4	6.875	±8.299	7.708	*±4.958
	14	1	.125	±1.245	.333	±1.305
		2	10.417	*±6.202	1.333	±1.400
		3	20.625	*±6.147	10.042	*±5.530
		4	−1.708	±2.002	3.125	*±2.947
	15	1	1.792	±4.350	2.375	±2.482
		2	−.583	±1.119	7.167	*±3.530
		3	−1.292	±1.846	15.917	*±4.100
		4	−10.208	*±6.126	2.667	±8.123
	16	1	−.208	±1.027	.417	±.809
		2	−.208	±1.594	.208	±1.027
		3	3.875	±6.604	2.417	±2.511
		4	−1.458	±7.341	−.917	±1.372
	19	1	−1.167	±1.609	1.208	±1.443
		2	−1.458	*±1.330	7.000	*±4.135
		3	1.667	±4.266	15.125	*±6.111
		4	−10.625	*±5.296	.625	±3.900
	23	1	.875	±1.614	1.250	*±1.197
		2	2.292	±3.282	7.625	*±4.092
		3	19.542	*±5.704	16.208	*±3.793
		4	3.500	±4.200	3.583	±4.061
	24	1	−.625	±1.754	1.000	±1.483
		2	−.542	±3.667	6.083	*±4.843
		3	8.625	*±6.793	15.125	*±4.752
		4	−11.292	*±5.841	1.000	±1.424
	29	1	2.167	±3.665	1.375	±1.528
		2	.833	±7.975	7.458	*±4.254
		3	6.750	±9.182	12.250	*±5.354
		4	−14.333	*±8.365	4.333	*±3.761
	30	1	2.167	±4.209	2.542	±2.540
		2	−.042	±.917	7.250	*±4.844
		3	−1.083	±2.013	15.667	±6.985
		4	−8.042	*±6.954	3.708	±5.630
	44	1	−3.167	±6.070	−.417	±.809
		2	−1.583	±2.862	.167	±.602
		3	−.458	±4.555	3.000	±3.897
		4	−12.333	*±5.635	−.833	±2.339

*Significant at the .01 level.

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